UDC 666.64:536.413.001.24

THERMOMECHANICAL CHARACTERISTICS OF POLYPHASE POROUS CERAMICS

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Translated from Steklo i Keramika, No. 12, pp. 20 – 21, December, 1998.

Experimental results of the thermal expansion of polyphase porous ceramics are presented. A method for determining the thermomechanical parameters is considered, and calculation formulas are provided. The results obtained can be used in thermal calculations involving polyphase ceramic materials.

After thermal treatment of ceramic construction materials, numerous pores emerge in articles, whose part by volume on average constitutes up to 30 – 40% [1 – 3]. Consequently, the gases (air) inside the pores of the fired ceramics materials in heating have a significant effect on their thermomechanic parameters (thermal expansion, coefficient of thermal linear expansion (TCLE)).

The present work describes the results of experimental and analytical investigations of thermomechanical properties of porous ceramics in heating.

Let us consider the investigated material as a two-phase solid-gas system. Taking into account the expansion of gases in the sealed pores, thermal deformation and the TCLE can be expressed in the following way:

$$\varepsilon_{sam} = k_1\varepsilon_s + k_2\varepsilon_g;$$

$$\alpha_{sam} = k_1\alpha_s + k_2\alpha_g,$$

where ε_{sam} and α_{sam} are thermal expansion and the TCLE of a porous ceramic sample, respectively; ε_s, α_s and ε_g, α_g are the same values for a poreless dense sample and for gas, respectively; k_1 and k_2 are the coefficients reflecting the contribution of the solid and gaseous phases to the expansion of the solid-gas system, in this case $k_1 + k_2 = 1$.

Next, let us consider the method for determining the coefficients k_1 and k_2:

$$\begin{cases} \alpha_{sam} = k_1\alpha_s + k_2\alpha_g; \\ k_1 + k_2 = 1. \end{cases}$$

By solving this system of equations, we obtain the expressions for the coefficients k_1 and k_2;

$$\begin{cases} k_1 = (\alpha_{sam} - \alpha_g)/(\alpha_s - \alpha_g); \\ k_2 = 1 - k_1. \end{cases}$$

Obviously, the thermomechanical parameters of a polyphase material can be established directly on the basis of experimental data, i.e., dilatometric measurements. Hence it follows that if we can determine these parameters for a poreless dense sample, it will be possible to reveal the effect of the gas sealed inside the pores on the expansion of the solid-gas system in heating. In order to determine the relative thermal expansion and the TCLE of the poreless dense ceramics, the following empirical formulas were used:

$$\varepsilon_s = a_1\varepsilon_1 + a_2\varepsilon_2 + \ldots + a_n\varepsilon_n; \quad (1)$$

$$\alpha_s = a_1\alpha_1 + a_2\alpha_2 + \ldots + a_n\alpha_n, \quad (2)$$

where ε_1, ε_2, ..., ε_n and α_1, α_2, ..., α_n are, respectively, the thermal expansion and the TCLE of the oxides constituting the solid part of the polyphase porous ceramics; a_1, a_2, ..., a_n is the fraction of the component oxides in the material, where $a_1 + a_2 + \ldots + a_n = 1$.

The relative thermal expansion and the TCLE of the oxides and air for different temperatures were found from the published data [4 – 6].

Model cylindrical samples 35 mm high and 15 mm in diameter plastically molded from clays of different chemical and mineralogic compositions were investigated: composition 1 — polymineral clay with predominance of kaolinite; composition 1 — polymineral clay with predominance of montmorillonite; composition 3 — Kerbulakskii loam. The chemical compositions of the samples are shown in Table 2.

The obtained samples were dried and fired at a temperature of 1000°C with isothermal holding of 30 min. The average density of the fired samples was 1800 kg/m^3.

TABLE 1

Sample	Mass content, %							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O
1	47.80	18.29	4.93	16.87	3.82	0.40	1.78	2.98
2	64.01	19.63	9.56	3.71	2.66	0.38	1.34	0.73
3	52.25	16.75	3.35	9.93	4.80	0.28	2.53	1.60

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0361-7610/98/1112-0384$20.00

TABLE 2

Sample	Mean values of TCLE, $10^{-6}\,°C^{-1}$ and k_1 and k_2 coefficients at temperature, °C														
	20 – 300					300 – 600					600 – 1000				
	α_{sam}	α_s	α_g	$k_1 \times 10^2$	$k_2 \times 10^2$	α_{sam}	α_s	α_g	$k_1 \times 10^2$	$k_2 \times 10^2$	α_{sam}	α_s	α_g	$k_1 \times 10^2$	$k_2 \times 10^2$
1	6.4	6.3	0.1	99.99	0.01	10.0	6.66	3.34	99.73	0.27	8.75	7.0	1.75	99.86	0.14
2	5.7	5.3	0.4	99.96	0.04	10.1	5.66	4.44	99.64	0.36	7.00	5.0	2.00	99.84	0.16
3	6.7	6.0	0.7	99.94	0.06	10.0	6.00	4.00	99.68	0.32	7.50	6.0	1.50	99.88	0.12

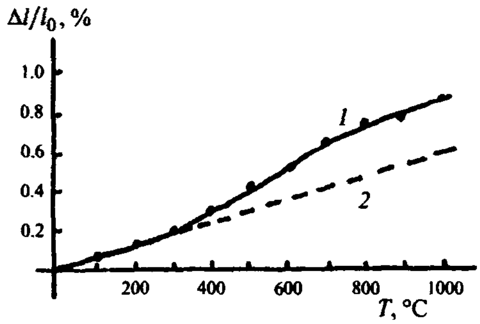

Fig. 1. Dilatometric curves of porous (*1*) and poreless dense (*2*) samples of the montmorillonite clay.

The experiments were performed on a special experimental device [7]. The samples were heated in a furnace at an average heating rate of 20°C/min.

Figure 1 shows the dilatometric curves for the composition 2 samples. Comparing the obtained curves, one can qualitatively and quantitatively evaluate the effect of the gas sealed inside the pores on the expansion of the solid-gas system. It can be seen that a perceptible effect of the gaseous phase on the expansion of the solid-gas system is observed beginning with 300°C.

The dilatometric curves of the investigated samples made of clays with different chemical and mineralogical compositions are qualitatively similar. Their quantitative differences are due to the difference in their chemical and mineralogical compositions and different ratios of the main clay-forming oxides.

In order to determine the average TCLE of the investigated samples $\bar{\alpha}_{sam}$ in different temperature intervals, the experimental data, i.e., the dilatometric curves, were used. The calculation of the average TCLE of a poreless dense sample $\bar{\alpha}_s$ was carried out according to formula (2). Knowing $\bar{\alpha}_{sam}$ and $\bar{\alpha}_s$, one can determine the TCLE of air $\bar{\alpha}_g$ sealed in the pores, i.e., the difference $\bar{\alpha}_{sam} - \bar{\alpha}_s$ characterizes the effect of the gaseous phase on the TCLE of the solid-gas system. The mean values of the TCLE of the samples are given in Table 2. The values of the coefficients k_1 and k_2 were determined for the typical temperature intervals.

The obtained results can be used for thermal calculations involved in the operation of polyphase ceramic materials.

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